

Effects of Gravitational Smearing on Predictions of Supergravity Grand Unification

T.Dasgupta, P.Mamales and Pran Nath

Department of Physics, Northeastern University, Boston, MA 02115

(February 1, 2008)

Abstract

Limits on gravitational smearing from the dominant dimension 5 operator (with strength characterised by $cM/2M_{Planck}$) are obtained using the LEP data in supersymmetric SU(5) grand unification. Effects of c on the quasi infrared fixed point solutions of m_b/m_τ unification are also analysed. It is found that $c > 0$ softens and $c < 0$ stiffens the fixed point constraint. The effect of c on the upper bound of the Higgs triplet mass is analysed and the existence of a scaling induced by c is discussed. Tests for the existence of gravitational smearing are discussed.

The high precision LEP data on the gauge coupling constants measured at the Z -scale [1] appear encouraging [2] for ideas of supersymmetry and grand unification and has spawned considerable activity towards extraction of further predictions from supersymmetric grand unification [3,4]. However it has been pointed out that gravitational smearing [5,6] from the unknown Planck scale physics may affect predictions of supersymmetric grand unification [7]. The analysis of Ref[7], however, was limited in that it used one loop renormalization group evolution, ignored the top mass dependence and did not include the constraints of b/τ unification. In this Letter we use LEP data to determine the allowed range of gravitational smearing parameter c using the full 2 loop renormalization group (R.G.) analysis of gauge coupling constants as well as two loop evolution of t, b, τ yukawas. We find that current data already puts important constraints on gravitational smearing. Simultaneously we analyse the effect of c on the quasi infrared fixed point solutions in the top quark yukawa coupling under the constraint that b/τ yukawas unify at the GUT scale[8,9,10]. The dependence of the upper bound on c is investigated and the phenomenon that the quantum gravity corrections generate an effective scaling of the heavy thresholds is discussed. We also emphasize that the gaugino sector involves an additional model dependent parameter c' which has the same origin as c but is in general numerically different. We discuss tests for determinations of c and c' .

The framework of the analysis we present here is the supergravity SU(5) model [11,12]. We assume that the GUT symmetry of this model is broken by the term $\lambda_1[\frac{1}{3}\Sigma^3 + \frac{1}{2}M\Sigma^2]$ while the Higgs triplet becomes superheavy and the Higgs doublets remain light via the interaction $\lambda_2 H_2[\Sigma + 2M']H_1$ [13], where $H_1(H_2)$ are $5(\bar{5})$ of Higgs and Σ is a 24-plet of SU(5). The superheavy fields after spontaneous breaking of the GUT symmetry consist of $(3, 2, 5/3) + (\bar{3}, 2, -5/3)$ massive vector bosons of mass $M_V = 5\sqrt{2}gM$, $(1, 3, 0) + (1, \bar{3}, 0)$ massive color Higgs triplets of mass $M_{H3} = 5\lambda_2 M$, $(1, 8, 0) + (1, 3, 0)$ massive Σ -fields of mass $M_\Sigma = 5\lambda_1 M/2$ and a singlet Σ field of mass $M_\Sigma/5$, where M enters in the VeV of Σ as $\langle \text{diag}(\Sigma) \rangle = M(2, 2, 2, -3, -3)$. In our analysis we use 2-loop evolution of gauge coupling constants which are given by [14]

$$\frac{d\gamma_i^{-1}}{dt} = \left[b_i + \sum_{j=1}^3 b_{ij}\gamma_j - \sum_{j=t,\beta,\tau} a_{ij}Y_j \right] \quad (1a)$$

where $\gamma_i = \alpha_i/4\pi$ ($\alpha_i = g_i^2/4\pi$), $Y_i = \lambda_i^2/16\pi^2$, $t=2\log(M_G/Q)$ and the b_i are given by

$$b_1 = \frac{33}{5} + b_{1lt} - 10\Theta_{\bar{V}} + \frac{2}{5}\Theta_{\bar{H}_3} \quad (1b)$$

$$b_2 = 1 + b_{2lt} + 2\Theta_{\bar{\Sigma}} - 6\Theta_{\bar{V}} \quad (1c)$$

$$b_3 = -3 + b_{3lt} + 3\Theta_{\bar{\Sigma}} - 4\Theta_{\bar{V}} + \Theta_{\bar{H}_3} \quad (1d)$$

where b_{ilt} are the corrections from the light thresholds, and $\Theta_{\bar{V}} \equiv \Theta(\mu - M_V)$ etc. We use the standard match and run technique between different thresholds and in going from $\bar{D}R$ to $\bar{M}S$ as we cross the highest SUSY threshold we use the correction $\Delta_{ic} = C_2(G_i)/12\pi$ where $C_2(G_i)$ is the quadratic Casimir.

We discuss next the influence of Planck scale physics on GUT analyses. These effects manifest by the appearance of higher (> 4) dimension operators at the scale of GUT physics. For example in N=1 supergravity the kinetic energy and mass terms for the gauge fields and the gaugino are given by [12]

$$\begin{aligned} e^{-1}\mathcal{L} = & -\frac{1}{4}\Re[f_{\alpha\beta}F_{\mu\nu}^{\alpha}F^{\beta\mu\nu}] + \frac{1}{4}i\Im[f_{\alpha\beta}F_{\mu\nu}^{\alpha}\tilde{F}^{\beta\mu\nu}] + \frac{1}{2}\Re\left[f_{\alpha\beta}\left(-\frac{1}{2}\bar{\lambda}^{\alpha}\not{p}\lambda^{\beta}\right)\right] \\ & -\frac{1}{8}i\Im\left[f_{\alpha\beta}e^{-1}D_{\mu}(e\bar{\lambda}^{\alpha}\gamma^{\mu}\gamma_5\lambda^{\beta})\right] + \frac{1}{4}\bar{e}^{G/2}G^a(G^{-1})_a^b(\partial f_{\alpha\beta}^*/\partial z^{*b}\lambda^{\alpha}\lambda^{\beta}) + \text{h.c.} \end{aligned} \quad (2)$$

where z^a are the scalar fields λ^{α} are the gauginos and the function G is given by $G = -\ln[\kappa^6 WW^*] - \kappa^2 d$, where W is the superpotential, $d(z, z^*)$ is the Kahler potential and $M_P = \kappa^{-1} = (8\pi G_N)^{1/2} = 0.41 \times 10^{-18}$ GeV where G_N is Newton's constant. Now in general $f_{\alpha\beta}$ can have a non-trivial field dependence and one may write $f_{\alpha\beta} = A\delta_{\alpha\beta} + Bd_{\alpha\beta\gamma}\Sigma^{\gamma}$, where $d_{\alpha\beta\gamma} = 2\text{tr}(\{\lambda_{\alpha}/2, \lambda_{\beta}/2\}\lambda_{\gamma}/2)$ and $\lambda_{\alpha}/2$ are matrices in the adjoint representation of SU(5) group generators, and Σ^{γ} is defined by $\Sigma_b^a = \Sigma^{\alpha}(\lambda_{\alpha}/\sqrt{2})_b^a$. After spontaneous breaking of supersymmetry via the hidden sector and the breaking of SU(5) to $SU(2)_L \times U(1) \times SU(3)_C$ from the VeV growth of Σ , one can carry out a rescaling to achieve a canonical kinetic energy for the gauge fields and the gaugino fields. One finds then a splitting of the gauge coupling constant at the GUT scale M_G (taken to be the highest mass threshold) so that

$\alpha_i^{-1}(M_G) = \alpha_G^{-1}(M_G) + c\epsilon_i$ where $\epsilon_i = n_i(\alpha_G)^{-1}M/(2M_P)$ and $n_i = (-1, -3, 2)$ for i in the $U(1) \times SU(2)_L \times SU(3)_C$ sectors. After rescaling the gaugino mass matrix is

$$m_{\alpha\beta} = \frac{1}{4}\bar{e}^{G/2}G^a(G^{-1})_a^b(\partial f_{\alpha\gamma}^*/\partial z^{*b})f_{\gamma\beta}^{-1} \quad (3)$$

Eq(3) can be reduced further. Thus writing $G^b(G^{-1})^ab = q_A D^{Aa}$ ($A=1,2$) where $D^{1a} = \delta^{az}$, $D^{2a} = \delta^{a\alpha}\Sigma_0^{*\alpha}$, defining $\vec{u} = (1, q_1, q_2)$, $\vec{v} = (2\Sigma_0^2 B'_\Sigma, B'_z, B)$ and $\vec{w} = (0, A'_z, 2\Sigma_0^2 A'_\Sigma)$ where $A'_z = (\partial A/\partial z)_0$, $A'_\Sigma = (\partial A/\partial \Sigma^2)_0$, and B'_z and B'_Σ are similarly defined, one finds that the gaugino masses are given by

$$\frac{M_i}{m_{1/2}} = \frac{\alpha_i}{\alpha_G} \left(1 + c' \frac{M}{M_P} n_i \right) \quad (4)$$

where $c' \equiv (u.v/u.w)$, in accord with the analysis of Ref[6]. We observe then that a new parameter c' enters the neutralino and chargino masses. Thus, for instance, the scaling mass relations which are known to hold over the a majority of the parameter space allowed by the radiative electro-weak symmetry breaking[15] are now modified because of eq(4) and one has

$$(1 + \Delta_1)m_{\tilde{W}_1} \simeq 2(1 + \Delta_2)m_{\tilde{Z}_1}, m_{\tilde{W}_1} \simeq m_{\tilde{Z}_2} \quad (5)$$

where $\Delta_1 = -3c'M/M_P$ and $\Delta_2 = \Delta_1/3$. Thus while the $m_{\tilde{W}_1} - m_{\tilde{Z}_2}$ scaling relation is unchanged, there can be a significant modification of the $m_{\tilde{W}_1} - m_{\tilde{Z}_1}$ scaling law depending on the value of c' . This modification will reveal the existence of c' and provide a measurement of it. We note that the effects of c in the R.G. analysis of gauge couplings appear on an equal footing to those of heavy thresholds. Thus the coupling constant evolution in the neighborhood of the heavy thresholds can be written as $\alpha_i^{-1}(Q) = \alpha_G^{-1} + C_{ia} \log(M_a/Q)$ where M_a are the heavy thresholds and C_{ia} can be read off from eq(1) and α_G is evaluated at M_G (which we take to be the M_{H_3} mass). Inclusion of quantum gravity effects modify this relation so that

$$\alpha_i^{-1}(Q) = \alpha_G^{-1} + \frac{cM}{2M_P} \alpha_G^{-1} n_i + C_{ia} \log \frac{M_a}{Q} \quad (6)$$

Now by a transformation $M_a = M_a^{eff} e^{\chi_a}$ one can absorb the quantum gravity correction by defining effective heavy thresholds so that $\alpha_i^{-1}(Q) = \alpha_G^{eff-1} + C_{ia} \log(M_a^{eff}/Q)$. Here α_G^{eff} is α_G evaluated at M_G^{eff} where $M_G^{eff} = M_G \exp(-5C_P)$, $C_P = (\frac{\pi c M}{M_P} \alpha_G^{-1})$ so that $(\alpha_G^{eff})^{-1} = \alpha_G^{-1} - (15/2\pi)C_P$. Thus c generates an effective scaling of the heavy masses which are described by

$$M_a^{eff} = M_a e^{-k_a C_P}; k_a = (-\frac{3}{5}, \frac{3}{10}, 5) \quad (7)$$

where $a=1,2,3$ refer to Σ, V, M_{H_3} masses. We shall refer to this scaling again when we discuss the numerical analysis of the R.G. equations. Thus at this level of the R.G. analysis quantum gravity effects can be masked by threshold corrections. The situation here is similar to the correspondence between the effects of the light thresholds and heavy thresholds [17]. We note that the effect of the c' term is not masked by threshold corrections as may be seen in eqs(4) and (5). The confusion between threshold effects and quantum gravity effects can also be removed if a $p \rightarrow \pi^0 e^+$ or a $p \rightarrow \bar{\nu} K^+$ decay mode was observed. Thus the $p \rightarrow \pi^0 e^+$ mode will determine M_V which combined with the determination of M_V^{eff} from R.G. analysis as discussed above gives on using eq(7)

$$c = \frac{100}{3} \sqrt{\frac{2}{\pi}} \alpha_G^{3/2} \frac{M_P}{M_V} \log \frac{M_V}{M_V^{eff}} \quad (8)$$

Eq(8) provides a clean determination of c since c' decouples in this mode. A similar relation holds for $M_{H_3}^{eff}$ and M_{H_3} as can be read off from eq(7). However, here the extraction of M_{H_3} from $p \rightarrow \bar{\nu} K$ mode depends also on c' which enters in the chargino mass on which the $p \rightarrow \bar{\nu} K$ decay mode depends. Thus a knowledge of the neutralino and chargino spectrum will be needed along with the p -decay data to fix both c and c' .

We discuss next the m_b/m_τ mass ratio. We have carried out this analysis on a seven dimensional space parametrized by $\alpha_G, M_\Sigma, M_V, M_{H_3}, M_{\text{susy}}, \tan \beta$, and c , where we have parametrized the low energy scales by one common scale M_{susy} . We use two-loop evolution between M_{susy} and the GUT scale. These solutions are then matched on to the solutions below the SUSY scale using the boundary condition $\lambda_t(M_{\text{SUSY}}^-) = \lambda_t(M_{\text{SUSY}}^+) \sin \beta$, and $\lambda_i(M_{\text{SUSY}}^-) = \lambda_i(M_{\text{SUSY}}^+) \cos \beta (i = b, \tau)$. We also take into account the GUT threshold

corrections in b/τ evolution [16]. In our analysis we used $\alpha_{em}^{-1}(M_Z) = 127.9 \pm 0.1$ and included an M_t dependence in $\sin^2 \theta_w$ via the equation [10] $\sin^2 \theta_w = 0.2324 \pm 0.0003 + \delta$ where $\delta = -0.92 \times 10^7 \text{GeV}^{-2} \Delta^2$ and $\Delta^2 = [(M_t^{\text{pole}})^2 - (143 \text{GeV})^2]$. The range of acceptable values of α_3 are taken to be 0.12 ± 0.01 . There are also constraints on M_Σ and M_{H_3} from perturbativity of the GUT Yukawa couplings which we assume to imply $\lambda_{1,2}^2/4\pi \leq 1/2$. We have used a value of $M_t = 174 \pm 16 \text{GeV}$ as indicated by the CDF data [18]. The $\pm 16 \text{GeV}$ variation of the top mass has significant effect on the analysis this dependence enters importantly via. R.G. effects

In the determination of the b/τ masses we used renormalization group evolution up to three-loop order in QCD and one-loop order in QED. The evolution from QCD is given by [8,19].

$$m_f(\mu) = \hat{m}_f \left(-\beta_1 \frac{\alpha_s(\mu)}{\pi} \right)^{-\gamma_1/\beta_1} \left\{ 1 + \frac{\beta_2}{\beta_1} \left(\frac{\gamma_1}{\beta_1} - \frac{\gamma_2}{\beta_2} \right) \frac{\alpha_s(\mu)}{\pi} + \frac{1}{2} \left[\frac{\beta_2^2}{\beta_1^2} \left(\frac{\gamma_1}{\beta_1} - \frac{\gamma_2}{\beta_2} \right)^2 - \frac{\beta_2^2}{\beta_1^2} \left(\frac{\gamma_1}{\beta_1} - \frac{\gamma_2}{\beta_2} \right) + \frac{\beta_3}{\beta_1} \left(\frac{\gamma_1}{\beta_1} - \frac{\gamma_3}{\beta_3} \right) \right] \left(\frac{\alpha_s(\mu)}{\pi} \right)^2 \right\} \quad (9)$$

where $\beta_i, \gamma_i (i = 1, 2, 3)$ are given by $\gamma_1 = 2$, $\gamma_2 = \frac{101}{12} - \frac{5}{18}n_f$, $\beta_1 = -\frac{11}{2} + \frac{1}{3}n_f$, $\beta_2 = -\frac{51}{4} + \frac{19}{12}n_f$ and β_3 and γ_3 are given by

$$\gamma_3 = \frac{1}{96} \left[3747 - (160\zeta(3)) + \frac{2216}{9}n_f - \frac{140}{27}n_f^2 \right]$$

$$\beta_3 = \frac{1}{64} \left[-2857 + \frac{5033}{9}n_f - \frac{325}{27}n_f^2 \right]$$

and the effect of QED corrections are determined by, $m_f(\mu) = m_f(\mu') \left(\frac{\alpha(\mu)}{\alpha(\mu')} \right)^{\gamma_0^{QED}/b_0^{QED}}$ where $b_0^{QED} = \frac{4}{3}(3 \sum Q_u^2 + 3 \sum Q_d^2 + \sum Q_e^2)$, $\gamma_0^{QED} = -3Q_f^2$ and

$$\alpha^{-1}(\mu) = \alpha_{em}^{-1} + \frac{1}{6\pi} - \frac{2}{3\pi} \sum_f Q_f^2 \ln \frac{\mu}{m_f} \theta(\mu - m_f)$$

Unlike the analysis of [8], the value of α_3 was determined self consistantly using eqs.(1) and (9).

We discuss now the major results of this paper. In Fig.1 we give a determination of the range of c using the LEP data on α_i under the combined constraints of gauge coupling with

and without b/τ unification, when M_{SUSY} lies in the range $M_Z - 10TeV, M_{H_3} \geq 1 \times 10^{16}$ and all other parameters are integrated out. One finds that values of c consistent with the 1σ LEP bound on α_3 lie in the range $-1.9 \leq c \leq 3.0$ ($-0.4 \leq c \leq 3.0$) with (without) b/τ unification. Thus remarkably the current LEP data already puts rather stringent bounds on c . Fig 1 also exhibits the fact that b/τ unification gives an upper bound on α_3 of $\alpha_3 \leq 0.12$ over the allowed domain of c . This upper limit holds for the m_b mass range $m_b \leq 4.8$ GeV. Fig. 2 shows the upper bound on M_{H_3} mass for various values of c . One finds that the upper bound depends sensitively on c and exhibits a scaling in c as anticipated in our discussion earlier (see the discussion following eq(6)). Fig. 2 shows that a $c > 0$ requires a larger M_{H_3} to generate the same $M_{H_3}^{eff}$ as for $c=0$. This is what the scaling relation of eq(7) implies. The magnification factor $M_{H_3}(c=1)/M_{H_3}(c=0)$ is also consistent with what eq(7) gives. We have analysed the effect of gravitational smearing on the infrared fixed point solutions of $M_t - \tan\beta$ that arise when one imposes b/τ unification. Results are exhibited in Fig.3 for several values of c and several values of α_3 . For $c=0$ we find the standard result that b/τ unification puts m_t close to its fixed point value. Positive values of c are found to help relax the fixed point constraints while negative values of c make the fixed point constraint even more stringent. These features persist for the range of b quark masses discussed above.

In conclusion we have discussed several phenomena due to the effect of gravitational smearing on analyses of supersymmetric SU(5) unification. Remarkably one finds that the current LEP data already restricts c to lie in a narrow range. We also discussed the effects on the constraints imposed by the infrared fixed point in the top yukawa coupling and analysed the effects of c on M_{H_3} . The existence of a scaling of GUT masses induced by c was discussed. The analysis gives an upper limit on α_3 of 0.12 over the entire allowed range of c when b/τ unification is imposed. Possible ways for the determination of both c and c' were discussed. Specifically it is proposed that a breakdown of $m_{\tilde{W}_1} - m_{\tilde{Z}_1}$ scaling relation[15], can help determine c' .

This research was supported in parts by NSF grant number PHY-19306906.

REFERENCES

- [1] M. Davier, Proc. Lepton-Photon High Energy Phys. Conference, Geneva, 1991 eds. S. Hegarty et. al. (World Scientific, Singapore, 1991); H. Bethke, Proc. XXVI Conf. on High Energy Physics, Dallas, 1992, ed. J. Sanford, AIP Proc. No. 272(1993).
- [2] P. Langacker, Proc. Pascos 90-Symposium, Eds. P. Nath and S. Reucroft (World Scientific, Singapore 1990); J. Ellis, S. Kelley and D. V. Nanopoulos, Phys. Lett. **B249**, Phys. Lett. **B260**, 447(1991); U. Amaldi, W. de Boer and H. Furstenau, Phys. Lett. **B260**, 447(1991); F. Anselmo, et. al., Nuovo Cim. **104A**,1817(1991); P. Langacker and N. Polonsky, Phys. Rev. **D47**, 4028(1993).
- [3] G. G. Ross and R. G. Roberts, Nucl. Phys. **B377**, 971(1992); R. Arnowitt and P. Nath, Phys. Rev. Lett. **69**, 725(1992); M. Drees and M. M. Nojiri, Nucl. Phys. **B369**, 54(1992); J. Lopez, D. V. Nanopoulos H. Pois and A. Zichichi, Phys. Lett. **B299**, 262(1993); G. L. Kane, C. Kolda, L. Roszkowski and J. Wells, Phys. Rev. **D49**, 6173(1994); D. J. Castano, E. J. Piard and P. Ramond Phys. Rev. **D49**, 4882(1994); V. Barger, M. S. Berger and P. Ohman and R. J. N. Philips, MAD/PH/842(1994);
- [4] For a review see, R. Arnowitt and P. Nath, Proc. 1993 Swieca Summer School (World Scientific, Singapore); W de Boer, Karlsruhe preprint IEKP-KA/94-01(94).
- [5] C. T. Hill, Phys. Lett. **B135**, 47(1984); Q. Shafi and C. Wetterich, Phys. Rev. Lett. **52**, 875(1984).
- [6] J. Ellis, K. Enqvist, D. V. Nanopoulos, and K. Tamvakis, Phys. Lett. **155B**, 381(1985); M. Drees, Phys. Lett. **B158**, 409(1985); Phys Rev. **D33**, 1468(1986).
- [7] L. J. Hall and U. Sarid, Phys. Rev. Lett. **70**, 2673(1993).
- [8] V. Barger, M. S. Berger and P. Ohman, Phys. Lett. **B314**, 351(1993).
- [9] W. Bardeen, M. Carena, S. Pokorski, and C. E. M. Wagner, Phys. Lett. **B320**, 110(1994).

- [10] P. Langacker and N. Polonsky, Phys. Rev. **D49**, 1454(1994).
- [11] A. H. Chamseddine, R. Arnowitt and P. Nath, Phys. Rev. Lett. **29**, 970(1982).
- [12] For a review see; P. Nath, R. Arnowitt and A. H. Chamseddine,”Applied N=1 Supergravity”,(World Scientific, Singapore 1984); H. P. Nilles, Phys. Rep. **110**,1(1985);H. Haber and G. Kane, Phys. Rep. **C117**,75 (1985).
- [13] S. Dimopoulos and H. Georgi, Nucl. Phys. **B193**, 150(1981); N. Sakai, Zeit. f. Phys. **C11**, 153(1981).
- [14] M. B. Einhorn and D. R. T. Jones, Nucl. Phys. **B196**, 475(1982).
- [15] P. Nath,and R. Arnowitt,Phys.Lett.**B289**,368(1992); R. Arnowitt and P. Nath in Ref[3].
- [16] B. D. Wright, MAD/PH/812(1994).
- [17] R. Barbieri and L. J. Hall, Phys. Rev. Lett.**68**,752(1992)
- [18] CDF Collaboration, Fermilab-Pub-94/097-E(1994).
- [19] H. Arason,D. J. Castano,E. J. Piard,and P. Ramond, Phys. Rev. **D47**, 232(1993).
- [20] R. Arnowitt and P. Nath, Phys.Rev. **D49**, 1479(1994); J. Hisano,H. Murayama, and T. Yanagida, Nucl.Phys. **B402**, 46(1993).

FIGURES

FIG. 1. Allowed ranges of α_3 as a function of c for $m_b = 4.8\text{GeV}$, $M_t = 174 \pm 16\text{GeV}$ and $M_{SUSY} < 10\text{TeV}$ and $M=10^{17}/(15)^{1/2}$. The dotted lines show the bounds on c coming from the LEP data ($\alpha_3 = 0.12 \pm 0.10$). Shaded (unshaded) areas are the regions allowed by R.G. analyses with (without) m_b/m_τ constraint.

FIG. 2. Allowed regions of α_3 and M_{H_3} for different values of c . The upper limit of α_3 is found to be insensitive to c due to the strong m_b/m_τ constraint while the lower limit is not strongly affected by the constraint. As anticipated the fig. exhibits scaling with c of the upper bound on M_{H_3} as well as of the size of the allowed regions (The shaded area corresponds to $-0.4 < c < 1.0$).

FIG. 3. Allowed range of M_t^{pole} as a function of $\tan\beta$ for $\alpha_3 = 0.105$ (dot), $\alpha_3 = 0.11$ (dash) and $\alpha_3 = 0.12$ (solid) ($m_b = 4.8\text{GeV}$ & $M_{SUSY} < 10\text{TeV}$). The shaded areas correspond to $c = 0$. We find that $c < 0.9$ is not allowed for $\alpha_3 = 0.105$ for $M_{SUSY} < 10\text{TeV}$. Within each region of fixed α_3 one finds that curves for $c > 0$ ($c < 0$) always lie higher (lower) than those for the $c=0$ case.

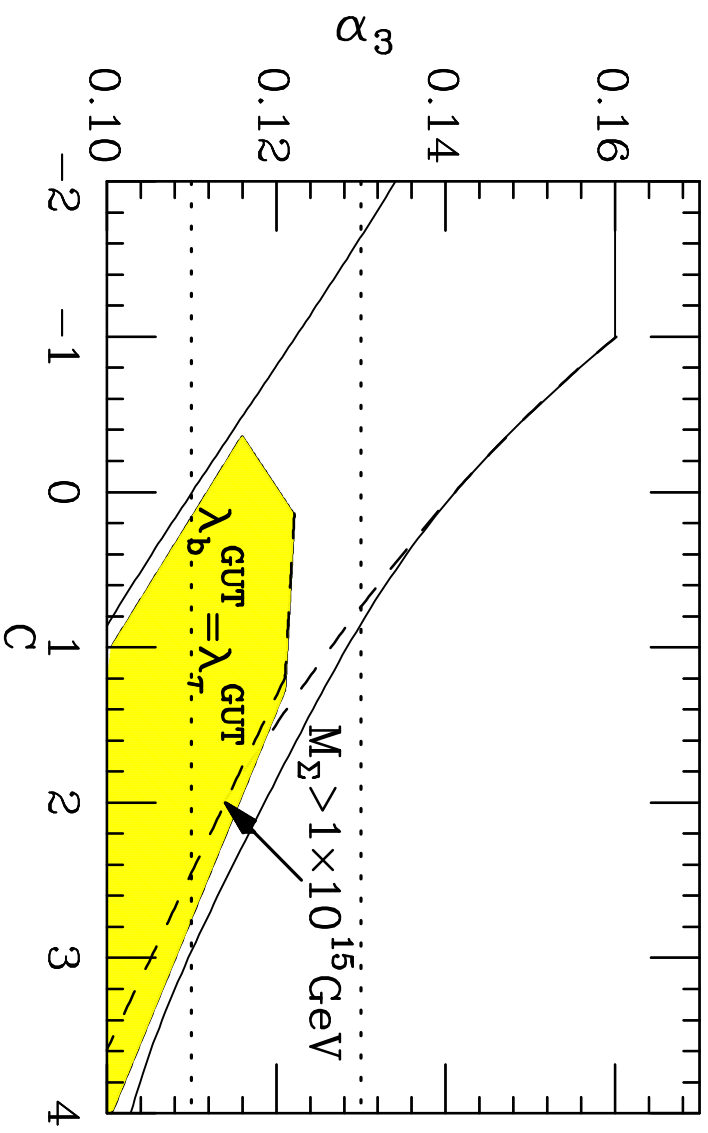


FIG. 1

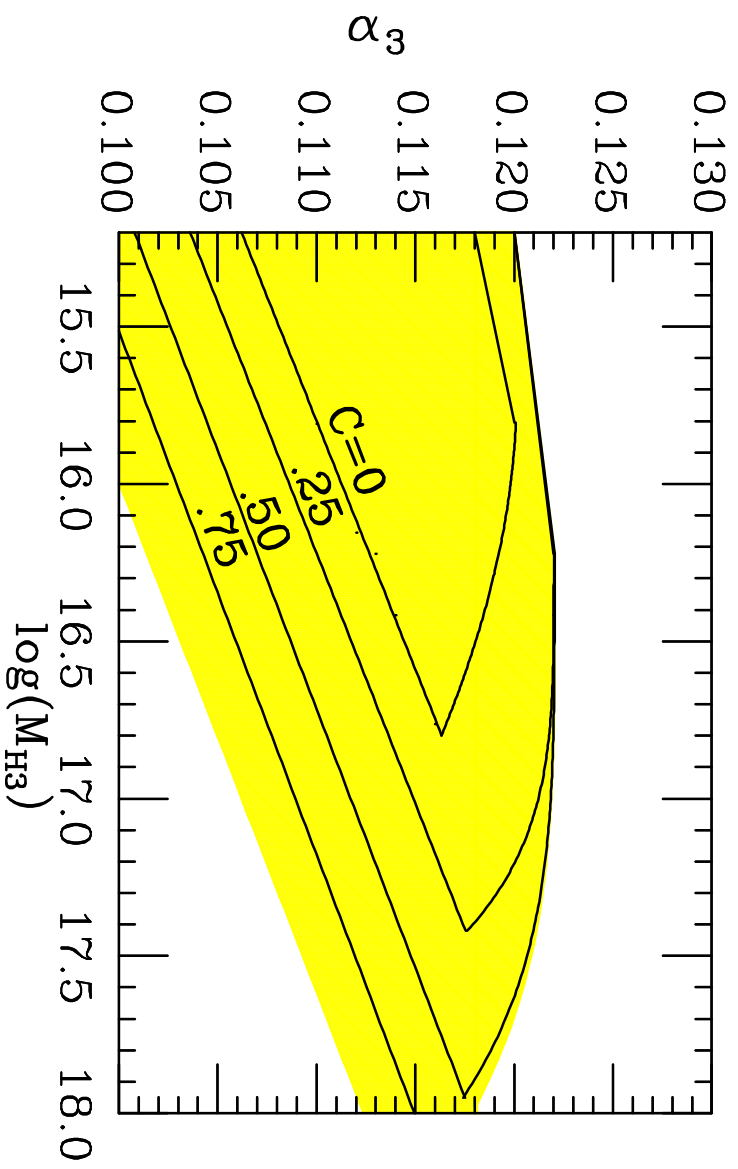


FIG. 2

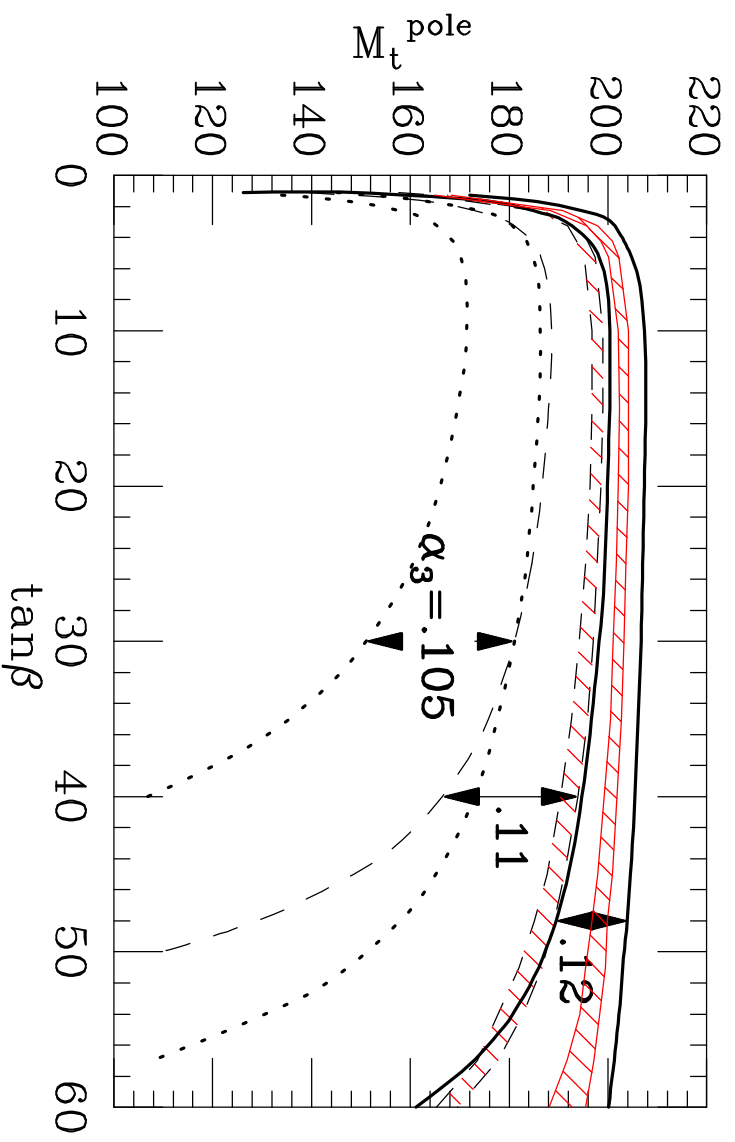


FIG. 3